"NOTICE: When Government or other drawings, specifications or other data are used for any purpose other than in connection with a definitely related Government procurement operation, the U.S. Government thereby incurs no responsibility, nor any obligation whatsoever; and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data is not to be regarded by implication or otherwise as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto."

8 cys

US ARMY MEDICAL RESEARCH LABORATORY

FORT KNOX, KENTUCKY

REPORT NO 400
16 September 1959

COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN. I. ABSOLUTE IDENTIFICATION OF STIMULUS INTENSITY LEVELS*

*Task under Psychophysiological Studies, USAMRL Project No. 6-95-20-001, Task Studies of Complex Behavioral Processes.

[redacted]

[redacted]

REPORT NO. 400

COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN. I. ABSOLUTE IDENTIFICATION OF STIMULUS INTENSITY LEVEL*

by

Glenn R. Hawkes
with the technical assistance of
Josl S. Warm

from

Psychology Division
US ARMY MEDICAL RESEARCH LABORATORY
FORT KNOX, KENTUCKY

*Task under Psychophysiological Studies, USAMRL Project No. 6-95-20-001, Task, Studies of Complex Behavioral Processes.

Report No. 400
Project No. 6-95-20-001
Task USAMRL T-5
MEOEA

ABSTRACT

COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN. I. ABSOLUTE IDENTIFICATION OF STIMULUS INTENSITY LEVEL

OBJECT

To determine the number of possible absolute identifications of current intensity levels in order to evaluate the usefulness of intensity as a cue in an electrical cutaneous communication system.

RESULTS

Intensity levels presented were equally spaced in terms of apparent magnitude of sensation within the range producing vibratory sensations but not pain. Subjects could absolutely identify two levels without error, with maximum transmission of information being achieved with the use of about three levels. More information was transmitted when a.c. was presented at 1500 cps than at 100 cps.

CONCLUSIONS

Two intensity levels would be useful in a communication system requiring perfect accuracy, while three levels would maximize transmission of information in a system which could tolerate some error.

RECOMMENDATIONS

A study should be made of the effect on information transmission of extended physical intensity range and immediate knowledge of results. Prior to such a study it would be necessary to determine what current intensities can be tolerated by the subjects without emotional reactions, and the reliability of such tolerance limits.

Submitted 28 July 1959 by:
Glenn R. Hawkes, 1st Lt, MSC
with the technical assistance of
Joel S. Warm, Pfc

APPROVED: Ernest K Montague
ERNEST K. MONTAGUE
Lt Colonel, MSC
Director, Paychology Diviaion

APPROVED: Floyd A. Odell
FLOYD A. ODELL
Technical Director of Research

APPROVED: Harold W. Glascock, Jr.
HAROLD W. GLASCOCK, JR.
Colonel, Medical Corps
Commanding

COMMUNICATION BY ELECTRICAL STIMULATION OF THE SKIN. I. ABSOLUTE IDENTIFICATION OF STIMULUS INTENSITY LEVEL

1. INTRODUCTION

The skin has often been considered a candidate for communication when the need arose to find a substitute for the eye or the ear. The Braille system, utilizing complicated patterns of spatially arranged touch stimuli, has made a vast array of literature available to the blind, but long training is required for its mastery and the delay involved in encoding material into Braille severely restricts information transmission speed.

Many attempts have been made to train subjects to "hear" directly via the skin, but on the whole without much success (4, 8, and 14). The basic difficulty with these studies has been the failure to appreciate the fact that the skin cannot make temporal discriminations as fine as those made by our better known receptors for sound energy, the ears. Geldard has pointed out, "No one paused to ask the skin what language it could compass. No one considered what... the tongue of the skin might be." (5). One should not assume that the sensory properties of the skin are so similar to those of the ear that nothing more than a little training is required to enable the immediate interpretation of speech applied directly to the skin. Rather, the first step is to assess cutaneous sensitivity to the types of signals likely to prove useful in communication. Geldard and his co-workers have done so for mechanical vibration.

A communication system using mechanical vibration of the skin was described by Geldard (5). Primary cues utilized in the system were three intensities of stimulation, five loci, and three stimulus durations. Combination of the cues afforded 45 different signals; the 26 letters of the alphabet were assigned to a like number of these signals, other cue combinations were used to stand for the 10 digits, with the remaining cue combinations available for short words such as "the" or "of." Maximum theoretical speed of this system was 67 words per minute for common prose samples. Training of subjects with the system demonstrated that these vibratory signals could be used for communication purposes.

An electrical cutaneous communication system analogous to that using mechanical vibration would have the advantage of providing a more easily controllable source of stimulation, as well as ease of design of the stimulator which rests on the skin. Electrodes are more easily

mounted on the skin's surface than are mechanical vibrators, and also are typically less bulky, thus affording less interference with normal movements. Further, for mechanical vibration the amount of power needed to energize the vibrators used was on the order of 10 w, as compared to only a tenth as much, or less, necessary for electrical stimulation of the skin.

In designing an electrical cutaneous communication system it remains to be seen what variety of signals is possible, but investigations should be made of those cues already demonstrated to be useful in the mechanical vibration system, viz., intensity of stimulation, duration of stimulation, and differing locus of stimulation. Since information is already available on the size of delta I for electrical currents, and since level of intensity is a primary cue used in the mechanical vibration system, intensity was selected as a logical topic for the present investigation.

Delta I/I values for electrical stimulation of the skin have been reported to be 0.052 at a standard intensity level of 120% of the absolute threshold current value, and 0.035 at a standard intensity of 200% of the absolute threshold value (6). This information on the size of the just noticeable difference (j n d) for intensity indicates the ability of the observer to detect a change in the stimulation 50% of the time. The rapid transmission speed needed in a communication system, as well as the need for signals that will not be confused with other signals, means that the ability of the observer to make absolute identifications of intensity levels must be investigated.

The use of intensity as a cue in the cutaneous communication system described by Geldard (5) was based on a study of the number of absolute judgments which can be made of intensity of mechanical cutaneous vibration (10). In this study a number of intensity levels were presented to the subject for identification, the number of such levels being changed until the 100% correct level was reached. The stimuli were equally spaced in terms of j n d's, i.e., they were a constant number of j n d's apart along the intensity dimension. The procedure of stimulus spacing by equal number of j n d's assumes equality in size of the j n d's, an assumption implicit in Fechner's formulation of psychophysical relationships. Investigations of a number of sensory continua by Stevens (11, 12, and 13) have demonstrated that j o d's are not necessarily subjectively equal.

Of the available techniques for attempting to evaluate directly the subjective magnitude of sensations, the method of "magnitude estimation" has been the one principally used by Stevens to examine sensory continua in an effort to relate them meaningfully to physical variations such

as changes of intensity of stimulation. Data on most of these continua have yielded functions which, plotted in log-log coordinates, may be fitted by a straight line whose slope is the exponent of a power function relating the physical dimension to apparent magnitude of the sensation. This is in contrast to the more traditional logarithmic function postulated by Fechner. The slope of the line which best fitted such data for intensity of electrical stimulation of the skin has been reported to be 3.5 by both Hawkes (6) and Stevens (13). Hawkes' results are reproduced in Figure 1.

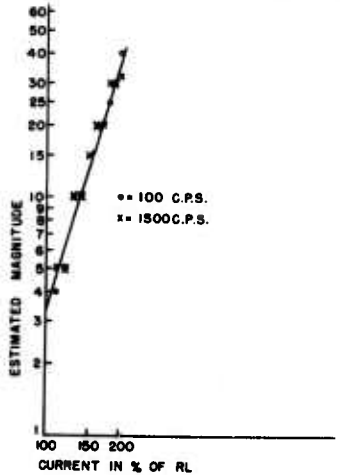

Fig. 1. Effect of current intensity on estimated magnitude of sensation for 2 frequencies of alternating current. Data from Hawkes (6).

In an investigation of the ability of the observer to make absolute identifications of current intensity levels the experimenter has a choice of two approaches. The stimuli can be placed a constant number of j n d's apart along the intensity range to be studied, or the stimuli may be an equal distance apart in terms of subjective magnitude. From the evidence accumulated by Stevens, it appears that a scale of subjective intensity would be more closely approximated by the direct estimation method than by the use of j n d's.

The number of possible absolute identifications of current intensity levels may be examined in regard to both the percentage of correct identifications and the amount of information transmitted by the subject. Information theory, considering the observer as a communication channel, predicts that an increase in the amount of input information results in an increase in information transmitted that eventually levels off at some asymptotic value. This asymptotic value has been termed by Miller (9) the "channel capacity" of the observer, and represents the maximum amount of information that he can give about the stimulus on the basis of an absolute judgment. The channel capacity, expressed in the number of bits of information transmitted, affords a measure of the optimum number of identifications which can be made along a given dimension of a number of stimulus alternatives; Garner and Hake (3) point out that any increase in the number of stimuli beyond this level results in increasing confusion and error.

Miller (9), in a review of reported data on information measurement, has stated that the accuracy with which subjects can absolutely identify unidimensional stimulus variables appears to be limited. He proposes that the limit for unidimensional absolute judgments appears to be about seven.

Investigations of the number of absolute identifications when the stimulus is mechanical vibration of the skin have indicated that the channel capacity for cutaneous stimulation may be less than the seven identifications (or, in terms of bits, about 2.6) suggested as typical in Miller's review (9). Spector (10) has reported that the number of 100% correctly absolutely identifiable intensity levels for mechanical cutaneous vibration is only three; he also reported that only three durations of stimulation could be correctly identified by all the subjects. A study of the channel capacity for judgments of rates of onset or offset of mechanical vibration was reported by Howell (7). His results show that the maximum transmission of information was reached with three rates of onset or offset, although his subjects could identify 100% correctly only two rates.

The present study was designed to determine the number of current intensity levels which could be absolutely identified with 100% accuracy, and the channel capacity for such stimuli. Knowledge of the number of intensity levels 100% correctly identified would be useful in the design of an electrical cutaneous communication system requiring perfect accuracy with minimal training, while knowledge of the number of levels which achieves maximum transmission of information would be useful in the design of a system which could tolerate some arror. The intensity levels used in this study we.e equally spaced in terms of apparent subjective magnitude of sensation according to the results shown in Figure 1 at the frequencias of stimulation for which data were reported, 100 cps and 1500 cps. The possibility of increasad information transmission incident to use of subjects with a high level of psychological sophistication was also investigated.

II. EXPERIMENTAL

A. Subjects

Twenty-four subjects participated in this experiment. Eighteen of them wera enlisted men stationed at the US Army Armor Center, Fort Knox, Kentucky; these subjects had no previous experisnca in the reporting of sensations elicited by the application of alternating current stimulation to the skin. This group was designated as "naive." The remaining six subjects were experimental psychologists of the US Army Medical Research Laboratory, Fort Knox, Kantucky. All members of this group had received a Ph. D. in Psycbology, and had participated in many psychological experiments. This group was designated as "sophisticated."

B. Apparatus

A block circuit diagram of the apparatus is shown in Figure 2, page 6. The circuit was completed by closing the switch interposed between the oscillator and the electronic switch. The electronic switch was designed to turn tha signal on and off at rates of onset and offset which avoided the production of transients. The Genaral Radio Type 978-R potentiometer controlled the amount of current through the subject. Current flow was computed from the voltage, measured with a Ballantine Type 300-D vacuum tube voltmeter, across a 100-ohm resistor in serias with tbe subject. Also in series with the subject during the experiment proper was a 500,000-ohm resistor to reduce fluctuations in the amount of current flow due to the changes in the skin rasistance of the subject. Stimulus wave form was monitored by a Du Mont type 304-A Cathode

Ray oecilloscope. The wave form remained sinusoidal for the frequencies and intensities used in this experiment.

One lead to the subject was attached to a circular electrode, 12 mm in diameter, which rested on the pad of the index finger of the subject, the other lead was attached to a 25 mm diameter circular electrode which rested on the palm. Both electrodes were coated with Medcraft Electrode Compound (manufactured by Medcraft Electronic Corp., Babylon, N. Y.).

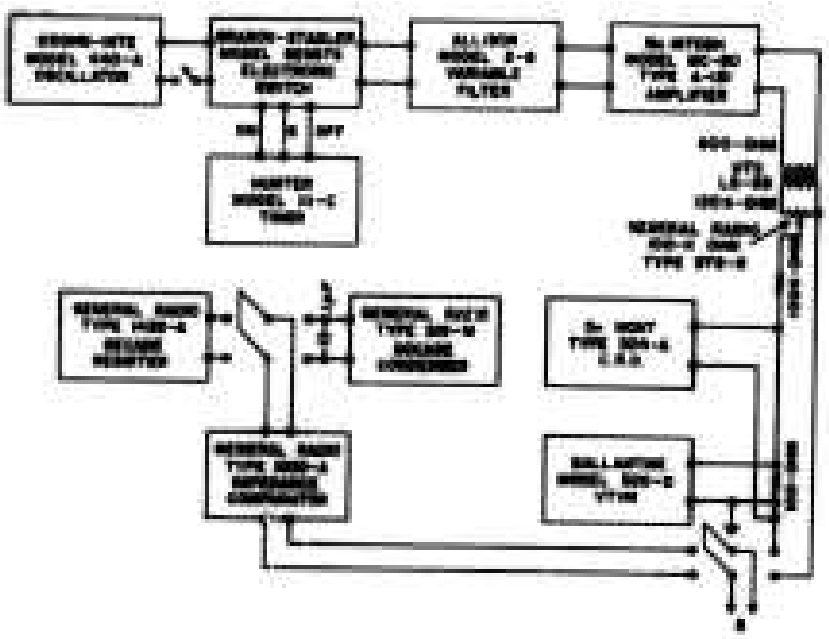

Fig. 2. Block circuit diagram of apparatus.

C. Procedure

Four sets of stimuli were selected for absolute identification of current intensity. The two-category set consisted of a low intensity level, just enough higher than the RL[1] of the subject to assure that it

[1] The abbreviation RL will be used to stand for the absolute threshold throughout this study.

would always remain above the RL for a series of judgments, and a high intensity level which was below the pain RL for most of the subjects; the values selected were 114% and 197% of the RL current value. The three-category stimuli were 114%, 170%, and 197% of the RL; the four-category stimuli were 114%, 155%, 180%, and 197% of the RL; the five-category stimuli were 114%, 148%, 170%, 185%, and 197% of the RL current. All stimuli were equally spaced in terms of equal subjective increments of sensation, according to the results shown in Figure 1.

Inter-subject and inter-session differences in current (ma) necessary to reach the absolute threshold were too great to permit use of the same absolute values of current throughout the experiment. Accordingly, the RL for a given subject was measured for each session, and stimulus intensity levels (in ma) selected which had a given ratio (in %) to the RL current value.

Twelve "naive" subjects were stimulated with a.c. at a frequency of 100 cps; 12 additional subjects received stimulation at 1500 cps. Six of the subjects in the 1500 cps group were "naive" and 6 were "sophisticated." Familiarization with electrical stimulation was given the subjects prior to the first experimental session to avoid any undue emotional reaction to stimulation by electrical current.

Each subject was given four sessions, with each different session being devoted to identification of a number of intensity levels. Six of the subjects of the 100 cps group, 3 subjects of the "naive" 1500 cps group, and 3 subjects of the "sophisticated" 1500 cps group, received five intensity levels during the first session, four levels during the second session, etc.; the remaining twelve subjects received two intensity levels during the first session, three levels during the second session, etc.

After measurement of the subject's RL for a given session, he was then presented 100 stimuli for identification, the stimuli being in a different random order for each subject and each session. The instructions were: "The purpose of this experiment is to determine how many levels of electrical intensity can be identified by human subjects. You are asked to identify two (or three, etc.) levels of intensity by responding '1' if you think it was the weak intensity level, or '2' if you think it was the strong intensity level. Here is number '1' (stimulation was presented), and here is number '2'; here is number '2' again (stimulation was presented again), and here is number '1'."

Before each stimulus presentation, the subject was warned by "ready," then the stimulus was turned on by the Hunter timer for 0.5 sec, after which the subject indicated the number which should be assigned to it. Stimuli were presented at a rate of about one every 2.5 sec, with a short rest interpolated between stimulus presentation number 50 and number 51. Sessions tended to average 30 min in length.

III. RESULTS

Mean values for the number of correct identifications for the 100 cps group are plotted in Figure 3. Comparison is made between subjects presented five categories in the first session and those presented two categories

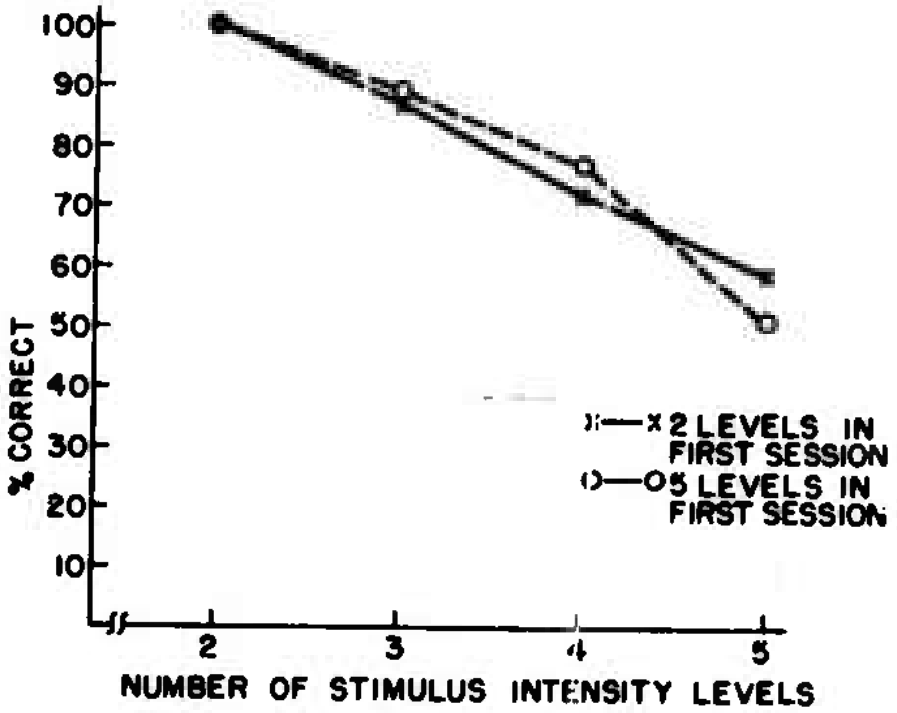

Fig. 3. Mean per cent correct identifications of current intensity levels. 100 cps.

in the first session. Per cent correct identifications for the 1500 cps group are plotted in Figure 4. Subject groups compared are "naive," "sophisticated," those presented five categories in the first session,

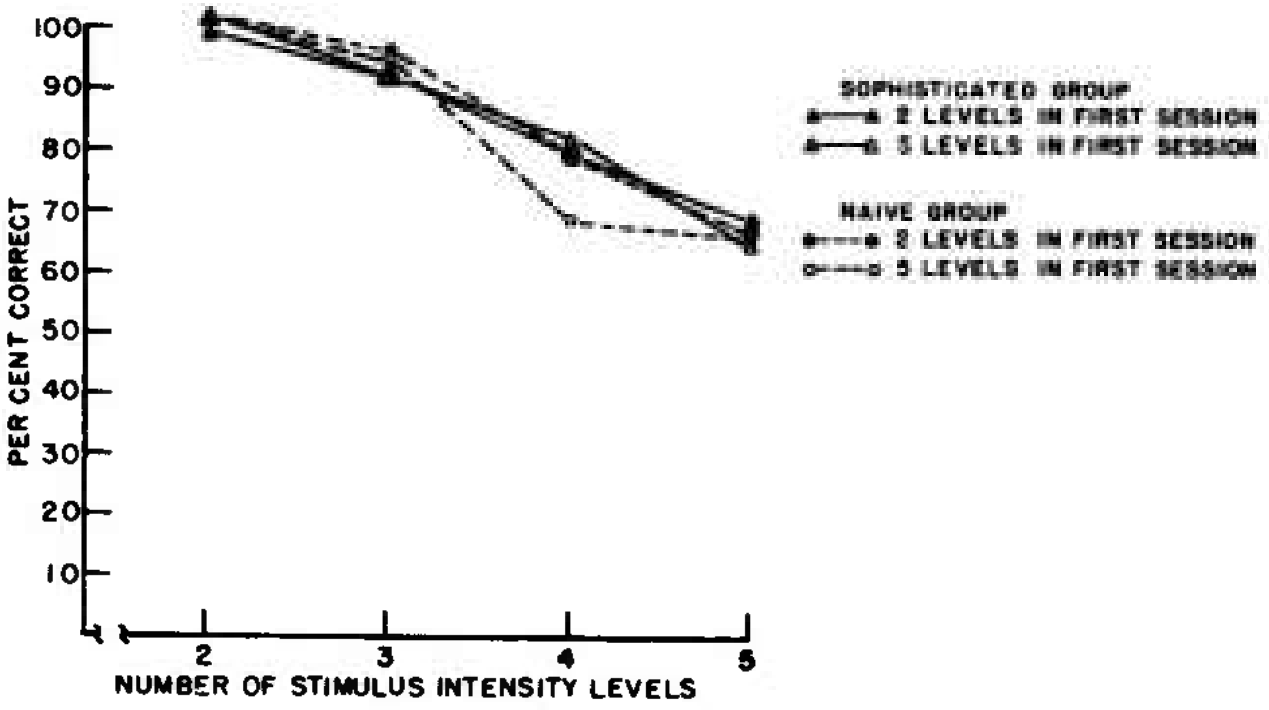

Fig. 4. Mean per cent correct identifications of current intensity levels. 1500 cps.

and those presented two categories in the first session. The number of correct identifications for individual sessions may be found in Tables 1 and 2.

TABLE 1

PER CENT CORRECT IDENTIFICATIONS OF CURRENT INTENSITY LEVELS. 100 cps

Subject	Levels in First Session	Number of Levels			
		2	3	4	5
1	2	100	88	88	62
2	2	100	84	77	85
3	2	100	83	70	59
4	2	89	90	71	44
5	2	100	80	78	80
6	2	100	83	63	84
7	5	100	87	88	66
8	5	100	70	71	39
9	5	100	84	80	51
10	5	100	90	72	48
11	5	100	88	85	47
12	5	100	83	84	55

TABLE 2

PER CENT CORRECT IDENTIFICATIONS OF CURRENT INTENSITY LEVELS. 1500 cps

Subject	Levels in First Session	Number of Levels			
		2	3	4	5
	Sophisticated Group				
13	2	100	85	88	88
14	2	87	84	80	56
15	2	100	83	89	76
16	5	100	87	71	61
17	5	96	86	81	81
18	5	100	86	90	71
	Naive Group				
19	2	100	87	72	66
20	2	100	94	79	84
21	2	100	96	87	88
22	5	100	97	84	74
23	5	100	84	6	66
24	5	100	85	39	54

The information transmitted as a function of number of intensity levels is plotted in Figure 5 for the 100 cps group, and in

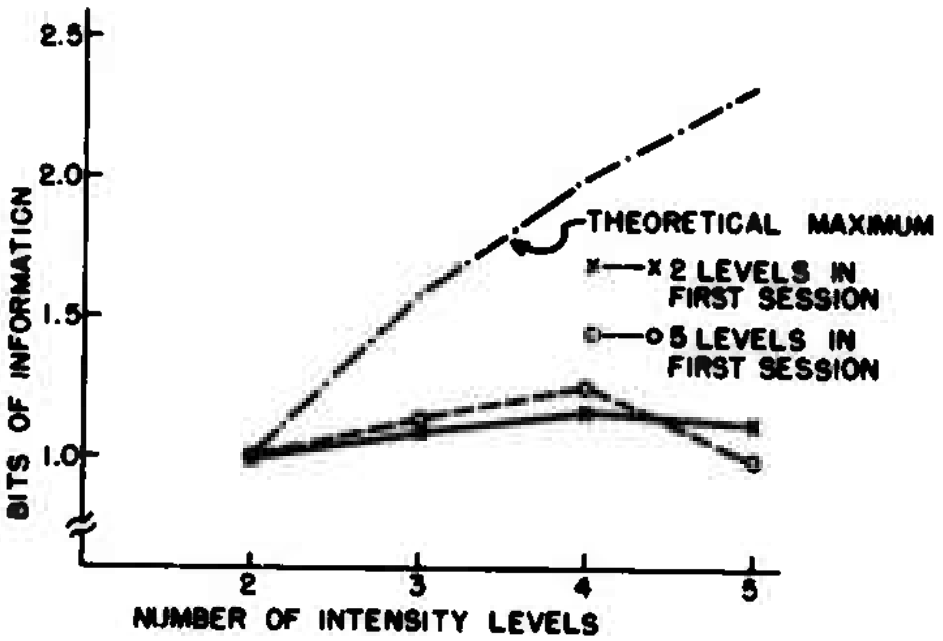

Fig. 5. Mean information transmitted as a function of number of current intensity levels. 100 cps.

Figure 6, page 12, for the 1500 cps group. Individual subject data are listed in Tables 3 and 4, page 13. Analysis of information transmitted was made according to a model described by Garner and Hake (3). Even though more stimulus information was available with four or five categories, transmission of information was only slightly greater than was reached by the use of only three levels of intensity.

A t-test for differences in the "amount of information transmitted by the average observer" (1) indicated that there was no significant difference between the 100 cps group which was presented two intensity levels in the first

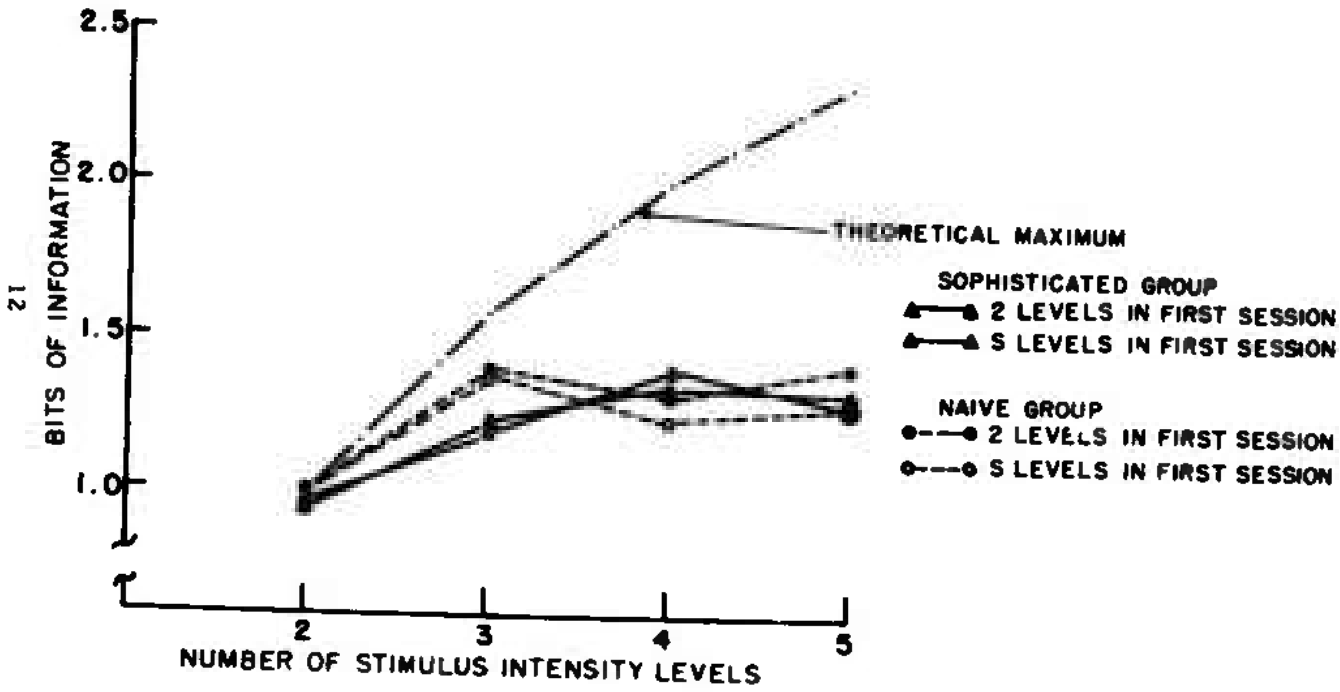

Fig. 6. Mean information transmitted as a function of number of current intensity levels. 1500 cps.

TABLE 3

BITS OF INFORMATION TRANSMITTED
AS A FUNCTION OF NUMBER OF
CURRENT INTENSITY LEVELS. 100 cps

Subject	Levels in First Session	Number of Levels				Mean
		2	3	4	5	
1	2	1.00	1.08	1.09	1.19	1.09
2	2	1.00	1.04	1.25	1.19	1.12
3	2	1.00	1.07	1.23	1.20	1.13
4	2	.93	1.19	1.08	.92	1.00
5	2	1.00	.99	1.29	.94	1.02
6	2	1.00	1.19	1.04	1.44	1.17
7	5	1.00	1.39	1.47	1.21	1.27
8	5	1.00	.79	1.42	.77	.99
9	5	1.00	1.30	1.29	1.09	1.19
10	5	1.00	1.10	1.02	.79	.99
11	5	1.00	1.09	.83	.99	.97
12	5	1.00	1.27	1.47	1.10	1.21

TABLE 4

BITS OF INFORMATION TRANSMITTED
AS A FUNCTION OF NUMBER OF
CURRENT INTENSITY LEVELS. 1500 cps

Subject	Levels in First Session	Number of Levels				Mean
		2	3	4	5	
	Sophisticated Group					
13	2	1.00	1.33	1.04	1.29	1.19
14	2	.93	.99	1.28	1.07	1.04
15	2	1.00	1.32	1.65	1.59	1.39
16	5	1.00	1.09	1.14	1.07	1.09
17	5	.93	1.40	1.43	1.43	1.30
18	5	1.00	1.11	1.59	1.32	1.25
	Naive Group					
19	2	1.00	1.40	1.14	1.24	1.20
20	2	1.00	1.31	1.29	1.41	1.25
21	2	1.00	1.45	1.50	1.54	1.37
22	5	1.00	1.44	1.40	1.47	1.33
23	5	1.00	1.31	1.24	1.24	1.20
24	5	1.00	1.37	1.01	1.10	1.12

session and those presented five levels in the first session (t = .14). Analysis of variance was made of the differences in information transmitted by the subjects of the 1500 cps group. the results are summarized in Table 5.

TABLE 5

ANALYSIS OF VARIANCE OF MEAN AMOUNT OF INFORMATION TRANSMITTED BY EACH SUBJECT
1500 cps

Source of Variation	df	Mean Square	F
Level of Sophisticotion (A)	1	.0051	.32
Order of Presentation (B)	1	.0013	.08
Interaction A x B	1	.0038	.24
Within Groups	8	.0160	
TOTAL	11		

Table 5 indicates that there was no significant difference in "information transmitted by the average observer" due to level of sophistication of the subjects ("sophisticated" vs. "naive"). There was no significant difference in information transmitted between the 1500 cps group which was presented two intensity levels in the first session and those presented five intensity levels in the first session. The interaction of level of sophisticotion and order of presentation also was not significant.

A t-test was made of the differences between the "amount of information transmitted by the average observer" for the 100 cps group and the group which received stimulation at 1500 cps. The t value of 2.99 was significant at the .01 level of confidence, demonstrating a significantly greater amount of information transmitted when the stimulation was presented at 1500 cps than when 100 cps was used.

IV. DISCUSSION

If, in a given situation, 100% correct performance is necessary for communication involving a.c. stimulation of the skin, then only two levels of intensity should be used. However, as Howell (7) has suggested in connection with mechanical cutaneous vibration, it is possible to take advantage of the fact that more information is transmitted by three categories than two if intensity level is combined with other cues to add redundancy to a message. Context might also help to reduce the number of incorrect responses due to occasional error if three intensity levels

were used in order to achieve maximum transmission of information. it is also possible that with proper training subjects could identify three levels 100% correctly.

Alluisi (1), in a review of several studies in audition and vision, has pointed out that immediate knowledge of results has been found to increase the amount of information transmitted. Knowledge of results might improve performance sufficiently to permit use of three intensity levels without error. Alluisi also reviewed several investigations which reported a gain in information transmitted as a result of extending the physical range of stimulation. A wider spacing of the stimuli used for identification might permit the use of three intensity levels, or more, without errors being produced thereby, as well as an increase in information transmitted. It is doubtful, however, that with greater spacing per se the channel capacity would be increased very greatly, since little increase was found to result from similar procedures in the studies reviewed by Miller (9).

Although the number of intensity levels which could be identified by the subjects of this experiment was considerably less than the seven which might be expected on the basis of Miller's review (9), the number found here was very close to that which has been found for a number of dimensions using mechanical vibration of the skin, as well as in other modalities such as taste (2). The small number of intensity levels which could be identified in this study compared to the number of identifications which can be made of auditory loudness, for example, might be due to some extent to the narrow range of physical intensities of current which could be used in the present experiment, dictated by the necessity of avoiding pain sensations on most of the subjects used. It has been suggested (6), that the narrow range of physical intensities which can be used for a. c. stimulation of the skin might be due to a different mode of operation of electrical current as opposed to adequate stimuli. It was postulated that electrical current operates directly on the cutaneous nerves, as well as on cutaneous receptors.

Intensity of stimulation, if used as a cue in an electrical cutaneous communication system, should be presented to subjects at a frequency of 1500 cps as opposed to 100 cps. The "naive" 1500 cps group was not different in any apparent way from the 100 cps group, and there was no significant difference in the information transmitted by the "naive" subjects as opposed to the "sophisticated" subjects. Therefore, the significantly greater transmission of information by the 1500 cps group must be assumed to be due to the use of a stimulus frequency of 1500 cps, rather than to differences between the subjects who participated in this study,

although some of the performance differential might be explained on the basis of individual differences.

V. CONCLUSIONS

Communication by stimulation of the skin has potential usefulness where the eye and ear are not available, as in cases of sensory impairment (the blind-deaf), when the receiver is in a high noise level situation (e.g., near jet aircraft), or where for secrecy purposes silence must be preserved, and in situations where a "unique" stimulation might be desirable (e.g., as a warning signal). Communication by mechanical vibration of the skin has been shown to be feasible, but electrical current has some advantages as a source of stimulation. Intensity of stimulation was one of the primary cues in the mechanical vibration system, three such levels being used since it was known that subjects could absolutely identify this number of levels with 100% accuracy.

The results of the present study indicate that subjects can absolutely identify two intensity levels of electrical current without error, and that maximum transmission of information is achieved with the use of only about three levels. Degree of psychological sophistication made no difference in the amount of information transmitted by the subjects, and no difference was found dependant on the number of intensity levels presented for identification in the first session.

The use of intensity level as a cue in an electrical cutaneous communication system requiring perfect accuracy should be restricted to two levels, but maximum transmission of information could be achieved by the use of three levels in a system which could tolerate some error. Stimulation should be presented at a frequency of 1500 cps, rather than 100 cps, since subjects in this experiment transmitted more information when this frequency was used.

VI. RECOMMENDATIONS

Additional studies should be made of the ability to make absolute identifications of current intensity levels using an extended physical intensity range and with immediate knowledge of results, these procedures having been reported to result in increased transmission of information in other experiments. Before a study can be made of the influence of extended physical range on the amount of information transmitted, an investigation should be made of the tolerance limit of subjects for a.c. stimulation of the skin, the relative reliability of this threshold, and of the possibility of using pain producing stimuli without causing undue emotional reaction on the part of the subjects.

VII. REFERENCES

1. Alluisi, E. A. Conditions affecting the amount of information in absolute judgments. Psychol. Rev. 64: 97, 1957.

2. Beebe-Center, J. G., M. S. Rogers, and D. N. O'Connell. Transmission of information about sucrose and saline solutions through the sense of taste. J. Psychol. 39: 157, 1955.

3. Garner, W. R. and H. W. Haka. The amount of information in absolute judgments. Psychol. Rev. 58: 446, 1951.

4. Gault, R. H. Hearing through sense organs of touch and vibration. J. Franklin Inst. 204: 329, 1927.

5. Geldard, F. A. Adventures in tactile literacy. Am. Psychologist, 12: 115, 1957.

6. Hawkes, G. R. Cutaneous discrimination of electrical intensity. Unpublished doctoral dissertation, Univ. of Virginia, 1959.

7. Howaii, W. C. Discrimination of rate of amplitude change in cutaneous vibration. Unpublished doctoral dissertation, Univ. of Virginia, 1958.

8. Katz, D. The vibratory sense and other lectures. Univ. Maine Stud. 14: 90, 1930.

9. Miller, G. A. The magical number seven, plus or minus two: some limits on our capacity for processing information. Psychol. Rev. 63: 81, 1956.

10. Spector, P. Cutaneous communications systems utilizing mechanical vibration. Unpublished doctoral dissertation, Univ. of Virginia, 1954.

11. Stevens, S. S. The direct estimation of sensory magnitudes: loudness. Am. J. Psychol. 69: 1, 1956.

12. Stevens, S. S. and E. H. Galanter. Ratio scales and category scales for a dozen perceptual continua. J. Exp. Psychol. 54: 377, 1957.

13. Stevens, S. S., A. S. Carton, and G M. Shickman. A scale of apparent intensity of electric shock. J. Exp. Psychol. 56: 328, 1958.

14. Wiener, N., J. B. Wiesner, E. E. David, Jr., and L. Levine. Operation "Felix." Quart. Progress Report, Research Lab of Electronics, Mass. Inst. Technol., 1949-51.

AFP-8949-O-Army-Knox-Sep 59-375